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Using Airphotos to Interpret Marbled Murrelet Nesting Habitat in British Columbia: Application of a Preliminary Classification Scheme

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EXECUTIVE SUMMARY

Airphoto interpretation can be used to assist land managers in identifying Marbled Murrelet (*Brachyramphus marmoratus*) nesting habitat in coastal British Columbia. Standards and procedures for using airphotos to assess habitat have now been drafted and these are based on recommendations prepared by the Canadian Marbled Murrelet Recovery Team (CMMRT). Through the study documented in this paper, we have assisted with the development of these standards by: 1) producing a collection of 47 reference airphotos of known murrelet sites for four Murrelet Conservation Regions; 2) describing the habitat parameter ranges and distributions estimated from the airphotos, and 3) identifying potential knowledge gaps and uncertainties with respect to interpreting murrelet habitat from airphotos.

Our report summarizes forest parameters interpreted at 274 murrelet sites located by either telemetry or ground-based methods in six study areas in coastal British Columbia. The preliminary habitat quality classification that we used has since been revised from five classes to six classes. The new scheme is believed to better reflect the CMMRT's height criterion. We discuss the relationship of the newer classification scheme to the original one and suggest the newer classification might yet be refined as habitat interpretation from airphotos is tested further. Therefore, reference photos may require updating in the future.

Given the broad range of habitats currently used by murrelets in coastal British Columbia, airphoto interpretation may not effectively identify all potential habitats; the use of additional methods is justified to help confirm habitat use, or to help rethink how well murrelets discriminate habitat and at what spatial scale. However, in general, airphoto interpretation shows promise for identifying murrelet habitat quality. Although we determined some differences between sites grouped by the different sampling methods, the overall parameter summaries and reference airphotos are nevertheless useful for guiding airphoto interpreters and land managers as to the range and distribution of habitat used by nesting murrelets.

KEYWORDS

marbled murrelet, *Brachyramphus marmoratus*, habitat associations, habitat quality classification, airphoto interpretation, forestry-wildlife habitat management, British Columbia

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INTRODUCTION AND OBJECTIVES

Airphoto interpretation can be used to identify Marbled Murrelet (*Brachyramphus marmoratus*) nesting habitat. In British Columbia, Lindsay and Leigh-Spencer (1999) were the first to use airphoto interpretation for this purpose, as a means of assisting land managers consider which areas to designate as reserves in land-management plans. Subsequent research (Bahn and Newsom 2002; Waterhouse et al. 2002) and review (Burger 2002) supported the potential of airphoto interpretation as a planning tool, and the Canadian Marbled Murrelet Recovery Team (CMMRT) recommended the use of airphoto interpretation to identify and assess the quality of potentially suitable nesting habitat prior to field assessments being undertaken (CMMRT 2003).

Standards and procedures for using airphotos to assess habitat have now been drafted by Donaldson (2003) and these are based on the CMMRT's recommendations. Through the study documented in this paper, we have assisted with the development of these standards by: 1) producing a collection of reference airphotos of known murrelet sites; 2) describing the habitat parameter ranges and distributions estimated from the airphotos, and describing the relationship of the habitat parameter ranges and distributions to a preliminary habitat classification scheme based on the CMMRT's classification scheme; and 3) identifying potential knowledge gaps and uncertainties with respect to interpreting murrelet habitat from airphotos.

STUDY AREAS

We used documented sites of potential nesting habitat from five of the six conservation regions proposed by the CMMRT (2003): the central mainland coast (CMC), Queen Charlotte Islands (QCI), west and north Vancouver Island, southeast Vancouver Island (SEVI), and southern mainland coast (SMC).[1] We divided west and north Vancouver Island into two subregions—western Vancouver Island (WVI) and northern Vancouver Island (NVI)—because we had relatively large samples of murrelet sites separately clustered in each of these areas (Table 1).[2]

Three biogeoclimatic zones are represented in the conservation regions/subregions: the Coastal Douglas-fir zone (CDF), the Coastal Western Hemlock zone (CWH), and the Mountain Hemlock zone (MH) (Meidinger and Pojar 1991). The CDF occurs mainly in the SEVI conservation region, from 0 to 150 m elevation. It is dominated by Douglas-fir (*Pseudotsuga menziesii*) and has a warm, dry climate. The CWH can also occur at the lowest elevations, or it can occur above the CDF. The dryer maritime variants of the CWH zone, which are in the rain shadow of coastal mountains, occur at elevations ranging from 0 to 650 m. The dry variants are dominated by Douglas-fir and western hemlock (*Tsuga heterophylla*), with lesser amounts of western redcedar (*Thuja plicata*) also occurring. The wetter variants of the CWH occur at elevations ranging from 0 to 1000 m. The wetter variants are often dominated by western hemlock and amabilis fir (*Abies amabilis*), with lesser amounts of western redcedar also occurring (Green and Klinka 1994). Smaller amounts of yellow-cedar (*Chamaecyparis nootkatensis*) and mountain hemlock (*Tsuga mertensiana*) occur within the CWH as elevation and wetness of the site increase. In the hypermaritime variants of the CWH, the amounts of western hemlock and amabilis fir decrease and the amount of cedar (red and/or yellow) increases as latitude increases. In the CWH, Sitka spruce (*Picea sitchensis*) is associated with wet sites such as coastal floodplain areas, and it occurs more commonly in the wet variants of the QCI, CMC, WVI, and NVI conservation regions/subregions. The MH zone occurs at higher elevations (usually >1000 m in the southern range, but as low as 400 m in the northern range), i.e., above the CWH. Forests in the MH zone are dominated by amabilis fir and mountain hemlock, although some yellow-cedar does occur (Green and Klinka 1994).

METHODS

Airphoto Samples

We compiled airphotos of murrelet sites that had been identified, by either telemetry or ground-based methods, as potentially used by murrelets for nesting (Table 1, Appendix B).

1. *Telemetry nest sites* were located by tracking a murrelet fitted with a radio attachment. Where possible, the nest tree was climbed to confirm the existence of a nest (Newman et al. 1999; Burger 2002). We refer to telemetry nest sites simply as *murrelet sites* unless we are making comparisons of the sites by the method.

2. *Ground-based murrelet sites* include nests located by tree climbing (random or non-random search methods) (Burger 2002) or sites located using audio-visual detection surveys (RIC 2001a and Evans Mack et al. 2003). As with the telemetry nest sites, we refer to ground-based murrelet sites simply as *murrelet sites* unless we are making comparisons of the sites by the method. We accepted those sites supplied to us on an airphoto if the contributor of the airphoto had high confidence that the location indicated probable use of the stand for nesting by murrelets. For those locations that could be confirmed only through the literature (Reimchen 1991; Materi et al. 1997, 1998; Rodway and Regehr 2002) we used only those for which we had a high confidence of the occurrence of nesting (Appendix B). These included

[1] Only the north coast conservation region was not represented.

[2] A list of abbreviations used in this report appears in Appendix A.

Table 1. Distribution of murrelet sites, as collected from airphotos.

Study area	Method of identification [a]	100-m radius plots (no.)	300-m radius plots [b] (no.)	Elevation range (m)	Biogeoclimatic subzones/variants
Central Mainland Coast (CMC)	Telemetry		8	110-650	CWHvm1/CWHvm2
Queen Charlotte Islands (QCI)	Telemetry	7	(7)	0-460	CWHvh2/wh1/wh2
	Ground (nest)	2	(2)	200	CWHwh1
	Ground		17	0-400	CWHvh2/wh1/wh2
Northern Vancouver Island (NVI)	Ground (nest)	2	(2)	30/~250	CWHvm1
	Ground		23	175-725	CWHvm1/vm2 (CWHmm1/xm2)
Southeast Vancouver Island (SEVI)	Ground (nest)	2	(2)	190-225	CWHxm1
	Ground		12	90-300	CWHxm1/CDFmm
Southern Mainland Coast (SMC)	Telemetry	102	(32)	129-1176	CWHvm1/vm2 (CWHdm/ MHmm1)
	Ground (nest)	11	(11)	600-1060	CWHvm1/vm2/MHmm1
	Ground		11	300-1060	CWHvm1/MHmm2
Western Vancouver Island (WVI)	Telemetry	34	(31) [c]	29-1191	CWHvm1/vm2 (CWHvh1/ MHmm1)
	Ground (nest)	8	(8)	0-600	CWHvh1/vm1
	Ground		35	4-760	CWHvh1/CWHvm1/vm2

[a] Ground-based methods - "ground" refers to sites identified by audio-visual detections or by ground search. The word 'nest' in brackets indicates a site where a nest was found when a tree was climbed, or where an observation strongly suggested a nest tree.

[b] Numbers in parentheses indicate that the 100-m plot is nested inside the 300-m plot.

[c] Telemetry subsamples by year for DS are: n=6 for 1998, 10 for 1999, 6 for 2000, 10 for 2001.
Telemetry subsamples by year for CS are: n=6 for 2000, 10 for 2001, 15 for 2002.

occupied sites, which as described by Evans Mack et al. (2003), are the ones that have nests, chicks, evidence of nests, or show evidence of subcanopy behaviour (flights at or below tree-top level, landing on/in a tree, or leaving a tree). We also used sites for which diving had been described, which may indicate pair behaviour (Evans Mack et al. 2003). In general, we used subcanopy flights as evidence of a site being used only when the flights were combined with either landing on or leaving a tree, or with diving. Caution is required when relying on subcanopy flights because they may merely indicate movement to other areas (Rodway and Regehr 2000; Evans Mack et al. 2003) rather than nesting. Samples from Dechesne and Smith (1997) were selected based on having the greatest number of audio-visual detections rather than on subcanopy behaviour because the latter was not provided. For these, and for samples from larger datasets (e.g., Burger;[3] Rodway and Regehr 2002), we selected subsamples to represent the distribution of areas

sampled within the dataset (Burger;[4] Manley 1999; Dechesne and Smith 1997).

If the sample areas of two or more sites overlapped, we used the actual nest location if it was available. Otherwise we randomly selected one of the two overlapping samples. Airphotos—colour, and black and white—were mostly mid scale (e.g., 1:10 000–1:20 000, with a few at 1:40 000). All the airphotos of the CMC study area were 1:40 000 scale, which limited our ability to interpret some parameters.

Sample Plots

Polygons (stands) of relatively uniform forest cover were mapped primarily from mid-scale airphotos that were taken for timber inventory purposes (RIC 2001b). These stands may not be sufficiently stratified if the spatial resolution of the interpretation and mapping is insufficient to show fine-scale variation in habitat selected by murrelets. To accommodate samples with differing precision in their locations, we used two plot sizes to estimate parameters within fixed-radius plots on the airphotos. Nests were usually marked accurately on airphotos. However, audio-visual detections were usually indicated merely within a general area outlined on the airphoto, which produces areas of varying size; or, the detection station was plotted but the locations of the detections were not plotted. We used 100-m radius plots (3 ha) centered on nests to capture the potential uncertainty associated with their estimated location on the airphotos (Waterhouse et al. 2002). For audio-visual detections, we used 300-m radius plots (28 ha) centered either within the area outlined on the airphoto or on the detection station. The large plot size accounts for the lower precision and greater uncertainty of the audio-visual locations within the stands. Three-hundred-metre radius plots were also used around a randomly selected subsample of telemetry nest sites (Table 1). The randomly selected subsamples were from Desolation Sound (DS; n=32) in the SMC study area, and from Clayoquot Sound (CS; n=31) in the WVI study area.

Interpretation of Sites

We described parameters associated with murrelet habitat use (Burger 2002; CMMRT 2003) and we used a habitat quality classification to rank the forest associated with the murrelet sites (Table 2). The habitat quality classification scheme discussed in this report is comprised of five classes that are based on the CMMRT's criteria. This habitat quality classification has since been revised and the classification is now comprised of six classes (Donaldson 2003). The six-class scheme is believed to better reflect the CMMRT's height criterion. We discuss the relationship of the newer classification scheme to the original one.

We also described additional novel stand parameters that may be associated with murrelet nesting habitat; this information is summarized in Appendix C. For the murrelet sites located using audio-visual detections, we assumed the forest cover >140 years old within the plot was the nesting habitat. Three plots (one from the QCI and two from NVI study areas) contained two distinct older forest types, both >250 years. In each case, for the compilation and analyses, we described the more productive forest type rather than the distinctly shorter and poorer type. For those stands with two or more layers,[5] we used the data associated with the top layer for analyses and compilation in this study.[6] We focused on the top layer because nest trees are typically described as the largest in the stand (Nelson 1997; Manley 1999; Burger 2002).

ANALYSES

Compilation of Samples

We used JMP (SAS 1995) for statistical calculations. We used three univariate analyses: Spearman rank correlation, non-parametric Wilcoxon sign-rank test, or the Pearson Chi-square / Fisher exact test for independence. Significant differences were considered at $P \leq 0.05$. We did not control for year in the analyses due to the small number of samples in some years; therefore our interpretations assume that year does not strongly bias patterns of habitat selection. To ensure the consistency of the results with CMMRT criteria, we summarized the results according to their parameter classes (Appendix D). We summarized samples by study area where potential regional differences were expected based on habitat availability (Burger 2002) and datasets.

We made two comparisons before determining how to compile the samples of murrelet sites that we had collected for each study area. These comparisons were important for understanding potential biases associated with our samples and methods, because we had only telemetry nest sites for the CMC study area; ground-based murrelet sites for the SEVI and NVI study areas; and datasets with varying proportions of telemetry nest sites and ground-based murrelet sites for the WVI, SMC, and QCI study areas. Telemetry methods may produce relatively unbiased samples of nest sites with respect to habitat at one geographic location (Bradley 2002). Telemetry datasets were obtained from individual studie for each study area. However, our ground-based sample for each study area included subsamples of murrelet sites from

[3] Dr. A. Burger, Dept. of Biology, University of Victoria, Victoria, BC; unpub. data.

[4] See Footnote 3.

[5] Where a layer is defined as a distinct group of trees based on stand age and height, and, for this study, on the stand having a minimum 5% crown closure instead of the 6% standard (RIC 2001b).

[6] Seventeen nest sites were defined as two-layer stands. Although the top layer likely describes potential nest trees, we caution that consideration may need to be given to the second layer because nests are often located in the lower two-thirds of the tree crown (Hamer and Nelson 1995).

Table 2. Parameters used to describe forest at murrelet sites on airphotos.[a]

Parameter	Definitions
Forest configuration	Patch: A forested area ≤30 ha, which on each side has a distinct edge that is a distance of at least one tree height in width (m) away from similar forested area. - Natural origin. Those patches surrounded by edges produced from avalanche chutes, riparian, scrub, or rock. - Harvest induced. Those patches surrounded with high contrast edges created by young forest stands or by recent harvesting. Continuous forest: All other forest configurations.
Forest cover >140 years old (%)	The percent of forest cover >140 years old (Age Classes 8 and 9) was estimated for the fixed area plot to describe the amount of potential forest associated with the murrelet nest or audio-visual detection. Less coverage indicates the site is located nearer to forest stand edges. Additional area in the plot was classified as % non-vegetated; % vegetated but non-treed; % of forest cover ≤140 years old (i.e., Age Classes 1-7). These parameters are not used in this report.
Habitat quality classification [b]	Classes below are defined in relation to benchmark stands, which are considered "best potential habitat" for the general study area. Stands are classified without consideration for patch size. *Very High*. Superior stand with large trees, large crowns, and excellent canopy structure. *High*. Good stand with large trees and good canopy structure. *Moderate*. Marginal stand with shorter trees and/or less canopy structure. *Low*. Poorly treed stands with no expected potential for murrelet habitat. *Nil*. Unforested areas.
Stand age	Average age (y) weighted by basal area of the dominant, co-dominant, and high intermediate of the leading species for each tree layer identified.
Tree height	Average height (m), weighted by basal area of the dominant, co-dominant, and high intermediate trees for the leading species of each tree layer identified.
Crown closure	Percent (%) estimate of the vertical projection of tree crowns upon the ground, by each tree layer identified.
Vertical complexity	Subjective classification that describes uniformity of the forest canopy by estimating the total difference in height of leading species and average tree layer height, and by describing occurrence of canopy gaps, past or recent disturbances, and stocking patterns. *Very Uniform*. <11% height difference. No evidence of canopy gaps or recent disturbance. *Uniform*. 11-20% height difference. Few canopy gaps may be visible, and little or no evidence of recent disturbance. *Moderately Uniform*. 21-30% height difference. Some canopy gaps may be visible. May be evidence of past disturbance. Stocking may be somewhat patchy or irregular. *Non-Uniform*. 31-40% height difference. Canopy gaps often visible (due to past disturbance). Stocking typically patchy or irregular. *Very Non-Uniform*. >40% height difference. Stocking is typically very patchy or irregular.

[a] See RIC (2001b), Waterhouse et al. (2002), and Donaldson (2003) for complete definitions and fit within overall classifications.

[b] Modified from Donaldson (2003). The classification in Donaldson has been revised to a proposed six-class scheme. The Very High class has not changed in the new classification, but the Low class is now split into Low and Very Low. And, more notably, use of tree height differs, such that a large proportion of sites ranked Moderate (based on tree height), become High.

many different studies. These studies took place at different locations, they had different objectives (research or management), and employed various sampling methods (random and non-random) (Appendix B).

First we determined whether interpretations of forest stands used by murrelets differed between the 100-m and the 300-m radius plots, because the ground-based murrelet sites identified by audio-visual detections were not interpreted with 100-m radius plots, while 300-m radius plots were applied only to a portion of the telemetry nest sites. For this analysis we used samples from the DS and CS datasets interpreted with both sizes of plots (Table 1). Second, we tested whether the telemetry nest sites and ground-based murrelet sites were similar and thus were representative of the same range of habitats used by murrelets. For this analysis we used locations sampled with 300-m radius plots and tested for differences between telemetry nest sites and ground-based murrelet sites collected within the WVI and SMC study areas. It was necessary to convert several parameters to binomial classes and/or remove observations as outliers for some tests. The analyses do not conclude whether the non-significant results are a response to the small sample size or if the results indicated no true difference.

Fit of Habitat Quality Classification

Using the telemetry nest sites from the DS and CS study areas (Table 3), we examined the fit of the preliminary habitat quality classification (Table 2) relative to a "likelihood scoring scheme". If the habitat quality classification (Table 2) strongly correlated with the CMMRT's criteria (Appendix D), then we expected the higher ranked sites to have higher likelihood scores. Because we were testing the classification with telemetry nest sites—and assuming the CMMRT's criteria are accurate—we expected most telemetry nest sites to both score and rank highly. We scored the telemetry nest sites by using the following five of the seven parameters recommended by the CCMRT (Appendix D):

1. elevation,
2. stand age class,
3. tree height class,
4. crown closure class, and
5. vertical complexity class.

We did not use site index productivity classes or distance to sea. Although elevation is not interpreted from airphotos, we included it because it is indirectly considered in the habitat quality classification whereas parameters (e.g., tree height) may change relative to elevation. We gave two points to values within the Most Likely class, one point for the Moderately Likely class, and 0 points for the Least Likely class (Table 3). We weighted all five parameters equally and totalled the points for each site to obtain an overall score (Table 3). A site with all five parameters ranked as Most Likely would score the maximum number of points (10), while a site with all five parameters ranked as Least Likely would score the minimum number of points (0).

We used cumulative frequency distribution curves as an exploratory approach for examining the distributions of scores relative to the CMMRT's criteria for classifying parameters, and relative to the habitat quality classification. We first produced cumulative distributions of telemetry nest sites using total scores from all five parameters (maximum score = 10) and identified the score required to include 90% of the telemetry nest sites. Next we produced cumulative distribution curves for combinations

Table 3. Likelihood scoring scheme for ranking habitat at telemetry nest sites.[a]

	Parameters				
Scoring scheme	Stand age (y)	Tree height (m)	Crown closure (%)	Vertical complexity classification	Elevation (m)
2 points (Most Likely)	>250	≥29	36-65	Moderately Uniform; Non-Uniform; Very Non-Uniform	0-900
1 point (Moderately Likely)	141-250	20-28	26-35; 66-75	Uniform	901-1500
0 points (Least Likely)	≤140	<20	>75; <26	Very Uniform	>1500

[a] The scheme uses point distributions for five parameters recommended by the CMMRT (2003) (Appendix D). Points are totalled for each site where a maximum score is 10 and a minimum score 0.

of four parameters (maximum score 8). We again assessed the score required to include 90% of the telemetry nest sites for each combination. For the combinations of the four and of the five parameters we calculated a relative index (RI).[7] If the relative index for a combination of four parameters is greater than the relative index for all five parameters we suggest that by eliminating the parameter we might improve the overall fit of the classification, because more telemetry nest sites would receive higher scores. If the relative index for four parameters is less than the five-parameter relative index, we suggest the eliminated parameter is useful for classifying telemetry nest sites because, with it excluded, fewer telemetry nest sites would receive higher scores. When interpreting the results from this exploratory approach, the reader should keep in mind that we weighted parameters equally and that we tabulated parameters of telemetry nest sites, but we did not assess usage relative to the availability of habitat types across the landscape.

RESULTS

Comparison of 100-m and 300-m Radius Plots

Spearman rank correlations (r) for continuous parameters, estimated within 100-m and 300-m radius plots that overlapped the same telemetry nest sites, were highly correlated for the DS and CS study areas (Table 4). Also, estimates of vertical complexity for the 100-m radius plots appeared to be similar to that of the 300-m radius plots; 91% of the overlapping samples had the same value, and no significant difference was revealed per the Chi-square test (P>0.10). But for the CS study area, although 81% of samples had the same values for the overlapping plots, a significant difference was indicated between the two (P=0.0001), and the raw data for these differences suggest that the 300-m radius plots are classified as more vertically complex than the 100-m radius plots. However, caution is needed in interpreting these results because the Chi-square test violated the 20% rule (Zar 1984).

Table 4. Spearman correlations coefficient (r) between parameter estimates of 100-m and 300-m radius plots for two study areas.[a]

	Study area	
	DS r	CS r
Forest cover >140 years old (%)	0.95*	0.72*
Stand age (y)	1.00*	0.96*
Tree height (m)	0.95*	0.88*
Crown closure (%)	0.93*	0.88*

[a] DS, n=32. CS, n=31.
* = All correlations were significant P≤0.05.

[7] Relative index (RI) = score for 90% of telemetry nest sites / maximum score.

Comparison of Telemetry Nest Sites and Ground-Based Murrelet Sites within the Southern Mainland Coast and Western Vancouver Island

For the 300-m radius plots, we found differences between the samples of telemetry nest sites and ground-based murrelet sites for the six parameters described in Table 2, but significant (P≤0.05) results and trends were not always consistent between the SMC and WVI study areas (Table 5). For the SMC and WVI study areas, in terms of forest configuration, only the telemetry method revealed that murrelets likely nested within patches (Table 5). The proportion (%) of forest cover >140 years old within the sample plots differed significantly between telemetry nest sites and ground-based murrelet sites for both the SMC and WVI study areas, but the relationship was not consistent. In both study areas, greater proportions of telemetry nest sites than ground-based murrelet sites had <40% of forest cover >140 years old, but the difference was greater for the SMC study area. Furthermore, in the SMC study area, a greater proportion of ground-based murrelet sites than telemetry nest sites occurred at sites with >80% of forest cover >140 years old. In contrast, in the WVI study area, a greater proportion of telemetry nest sites than ground-based murrelet sites occurred at sites with >80% of forest cover >140 years old (Table 5).

Of the sample of telemetry nest sites from the SMC study area, 25% occurred in ≤250-year-old stands and 25% in stands with <36% crown closure, but ground-based murrelet sites did not occur in either type of stand (Table 5). In the WVI study area, no differences were detected between the samples of telemetry nest sites and ground-based murrelet sites for age or crown closure. Tree height, in turn, differed significantly only for the WVI study area. While 55% of ground-based murrelet sites had trees in the >37 m height class, the telemetry nest sites had none (Table 5). For both the WVI and SMC study areas, distributions of telemetry nest sites and ground-based murrelet sites differed significantly for habitat quality classes, with smaller proportions of the sample of telemetry nest sites than ground-based murrelet sites occurring in higher quality classes (Table 5).

Parameter Summaries, by Study Area

After we identified the potential differences between the habitats sampled by telemetry and ground-based methods, we compiled separate datasets for telemetry nest sites and ground-based murrelet sites (Tables 6 to 12). We used the 100-m radius plots to maximize the sample size of telemetry nest sites. The samples of ground-based

murrelet sites were summarized using the 300-m radius plots. (The proportion of samples by method for SMC and WVI will differ from those reported in Table 5 because of sample size differences.)

Likelihood Scores

For each of our five parameters listed in Table 3, telemetry nest sites usually occurred within the Most Likely or Moderately Likely habitat classes (Table 13). However, some parameters at telemetry nest sites also occurred within the Least Likely classes (CS 0–8.8%; DS 9.8–18.6%) (Table 13). Overall, 12% of the telemetry nest sites in the CS study area and 33% of telemetry nest sites in the DS study area included at least one parameter in the Least Likely class. The total likelihood scores ranged between 3 and 10 for telemetry nest sites in the CS study area (Figure 1) and between 0 and 10 for the telemetry nest sites in the DS study area (Figure 1). The cumulative distribution curves of the scores indicated 90% of telemetry nest sites in the CS study area scored ≥6.8 (RI=6.8/10=0.68), while 90% of telemetry nest sites in the DS study area scored ≥5.1 (RI=0.51) (Figure 1). These overall likelihood scores (i.e., 6.8 for CS and 5.1 for DS) included some individual parameters that were valued as 0 points.

The relative indices calculated for telemetry nest sites in the CS study area (Figure 2a) indicated that more nests would score higher with the elimination of crown closure or height. (Relative indices were 0.78 for crown closure and 0.75 for height, i.e., greater than the relative index of 0.68 for all five parameters). For telemetry nest sites in the CS study area, elimination of elevation (RI=0.62), or vertical complexity (RI=0.56), or age (RI=0.56) reduced the number of higher scoring telemetry nest sites. For the DS study area, the relative indices for the cumulative distribution curves of four parameters (Figure 2b) indicated that more telemetry nest sites would score higher with the elimination of either height, age, or crown closure. (RIs were 0.62 for height, 0.56 for age, and 0.53 for crown closure, i.e., greater than the relative index of 0.51 for all five parameters). In turn, exclusion of vertical complexity (RI=0.41) or elevation (RI=0.44) would reduce the number of telemetry nest sites with higher scores.

Likelihood Scores Compared to Habitat Quality Classification

No telemetry nest sites in the CS study area ranked Very High according to the habitat quality classes described in Table 2 (Figure 3a). A portion of telemetry nest sites in the DS study area ranked Very High, and all had likelihood scores of 10 (Table 3, Figure 3b). Both the CS and DS study areas had telemetry nest sites that ranked High, and these scored 8 to 10, with all parameters scoring 1 to 2 except for a telemetry nest site in the DS study area for which one parameter scored 0 and the other parameters scored 2 each (Table 3, Figures 3a and 3b). For the CS and DS study areas, telemetry nest sites that ranked as Moderate or Low had the greatest range of likelihood scores, which suggests these classes had a broader range in interpretation outside of the parameters identified by the CMMRT (Figures 3a and 3b). Only a few telemetry nest sites in the CS study area ranked Nil and the relationship to likelihood scoring was unclear because nests scored between 3 and 6. In contrast, few telemetry nest sites in the DS study area ranked Nil and all had low likelihood scores (0–3).

DISCUSSION

Parameters for Describing Murrelet Nesting Habitat: Compilation Development

Parameters described in 100-m radius plots appeared to be similarly described in the 300-m radius plots. Thus the choice of plot size used in the compilations of the telemetry nest sites and ground-based murrelet sites should not create concerns about the habitats being interpreted at different scales (i.e., 3-ha and 28-ha plots). But we caution that we may not have adequately captured differences because of the small sample size; and, if parameters are not always equally distributed over the stand, estimates could change with plot area.

Telemetry nest sites and ground-based murrelet sites clearly differed with respect to certain parameters and the preliminary habitat quality classification. The ground-based murrelet sites encompassed a narrower range of habitats. This difference was greatest with respect to habitat quality classification, where greater proportions of the sample of ground-based murrelet sites were classified as High or higher quality habitats than those in the sample of telemetry nest sites. It is not surprising that ground-based nests ranked higher, because the MMRT rankings were based primarily on the collective experience of ground-based studies. However, the differences in rankings of murrelet sites by habitat quality classes may not be as apparent with Donaldson's (2003) new classification, because current testing with the telemetry nest sites from the DS study area suggests a large proportion of those ranked Moderate with the preliminary classification would instead rank High. Using Donaldson (2003), the sample of SMC telemetry nest sites becomes 52% (Very High and High), Moderate (26%), Low (16%), Very Low (7%), and Nil (1%). We do not have the same comparison for ground-based murrelet sites for the SMC but we expect the shift may be similar. We suggest four main reasons why the results indicated that the ground-based murrelet sites and the telemetry nest sites differed.

First, the sample of ground-based murrelet sites was not a random sample but a compilation of murrelet sites from a variety of studies that used a variety of methods to detect murrelets (Appendix B). Some of these ground-based studies focused on research and/or management

Table 5. Significant (P≤0.05) results of two-tailed tests[a] of parameter estimates in 300-m radius plots, for telemetry and ground-based sites in two study areas.

Parameter	Study area	Telemetry nest sites (n=32 for SMC, n=31 for WVI) [d]	Ground-based murrelet sites (n = 22 for SMC, n=43 for WVI) [d]	P
Forest configuration	SMC	31% patch 69% continuous	0% patch 100% continuous	0.003
	WVI	6% patch 94% continuous	0% patch 100% continuous	0.09
Forest cover >140 years old (%) [b]	SMC	0-40% = 41% 41-80% = 34% 81-100% = 25%	0-40% = 5% 41-80% = 27% 81-100% = 68%	0.002
	WVI	0-40% = 6% 41-80% = 15% 81-100% = 79%	0-40% = 2% 41-80% = 65% 81-100% = 33%	0.02
Stand age (y) [b]	SMC	81-250 y = 25% >250 y = 75%	100% >250 y	0.02
	WVI	81-250 y = 3% >250 y = 97%	100% >250 y	0.23
Tree height (m) [b]	SMC	≤28 m = 31% 29-37 m = 59% >37 m = 9%	≤28 m = 18% 29-37 m = 77% >37 m = 5%	0.89
	WVI	≤28 m = 26% 29-37 m = 74% >37 m = 0%	≤28 m = 5% 29-37 m = 40% >37 m = 55%	<0.0001
Crown closure (%) [b]	SMC	<36% = 25% 36-65% = 75%	<36% = 0% 36-65% = 100%	0.02
	WVI	<36% = 10% 36-65% = 77% >66% = 13%	<36% = 12% 36-65% = 86% >66% = 2%	0.20 [e]
Habitat quality [b,c]	SMC	High = 28% Mod = 50% Low = 22%	High = 55% Mod = 45% Low = 0%	0.03
	WVI	High = 29% Mod = 45% Low = 26%	High = 91% Mod = 9% Low = 0%	<0.0001

[a] Wilcoxon sign-rank, Pearson Chi-square, or Fisher's Exact tests.
[b] Parameter classes reduced for test.
[c] For our comparisons of habitat quality classes, we combined the Very High and the High classes into one class called High, and we combined the Low and the Nil classes into one class called Low.
[d] n is the total number of sites per study area for the telemetry or ground-based datasets.
[e] Violates 20% rule (Zar 1984).

Table 6. Proportion of murrelet sites, by forest configuration class.

Study area	Dataset	n [a]	Class [b] Patch (%)	Class [b] Continuous (%)	Comments
CMC	Telemetry	8	37.5	62.5	Sites occurred in patches for all study areas except NVI. Most were of natural origin except SMC–which had a small portion of harvest-induced patches (6/102)–and SEVI–for which both patches (2/14) were harvest induced.
	Ground-based	0	-	-	
QCI	Telemetry	7	14.3	85.7	
	Ground-based	19	15.8	78.9	
NVI	Telemetry	0	-	-	
	Ground-based	25	0.0	100.0	
SEVI	Telemetry	0	-	-	
	Ground-based	14	14.3	85.7	
SMC	Telemetry	102	28.4	71.6	
	Ground-based	22	0.0	100.0	
WVI	Telemetry	34	5.9	94.1	
	Ground-based	43	0.0	100.0	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table 7. Proportion of murrelet sites within percent classes of forest cover >140 years old.

Study area	Dataset	n [a]	Class [b] 0-40% (%)	Class [b] 41-80% (%)	Class [b] 81-99% (%)	Class [b] 100% (%)	Comments
CMC	Telemetry	8	0.0	50.0	25.0	25.0	Amount of forest cover >140 years old varies at murrelet sites for most study areas.
	Ground-based	0	-	-	-	-	
QCI	Telemetry	7	28.6	28.6	28.6	14.3	
	Ground-based	19	5.3	26.3	15.8	52.6	
NVI	Telemetry	0	-	-	-	-	
	Ground-based	25	16.0	28.0	24.0	32.0	
SEVI	Telemetry	0	-	-	-	-	
	Ground-based	14	0.0	42.9	42.9	14.3	
SMC	Telemetry	102	24.7	39.6	11.9	23.8	
	Ground-based	22	4.5	27.3	40.9	27.3	
WVI	Telemetry	34	5.9	14.7	17.6	61.8	
	Ground-based	43	2.3	58.1	7.0	32.6	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table 8. Proportion of murrelet sites, by stand habitat quality class.

Study area	Dataset	n [a]	Class [b] Nil (%)	Low (%)	Mod (%)	High (%)	Very High (%)	Comments
CMC	Telemetry	8	0.0	25.0	75.0	0.0	0.0	Most sites occur in Moderate to Very High quality habitats; but sites also occur in Low and Nil quality habitats (telemetry–CMC, SMC, WVI) which indicates some variation in stand use. Sites in the CMC study area did not classify as High or Moderate but this may be attributable to 1:40 000 airphotos.
	Ground-based	0	-	-	-	-	-	
QCI	Telemetry	7	0.0	0.0	57.1	0.0	42.9	
	Ground-based	19	0.0	0.0	10.5	42.1	47.4	
NVI	Telemetry	0	-	-	-	-	-	
	Ground-based	25	0.0	0.0	16.0	52.0	32.0	
SEVI	Telemetry	0	-	-	-	-	-	
	Ground-based	14	0.0	0.0	0.0	50.0	50.0	
SMC	Telemetry	102	2.0	25.5	45.1	20.6	6.9	
	Ground-based	22	0.0	0.0	45.5	40.9	13.6	
WVI	Telemetry	34	8.8	17.6	47.1	26.5	0.0	
	Ground-based	43	0.0	0.0	9.3	46.5	44.1	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table 9. Proportion of murrelet sites, by stand age class.

Study area	Dataset	n [a]	Class [b] 41-80 (y)	81-140 (y)	141-250 (y)	>250 (y)	Comments
CMC	Telemetry	8	0.0	0.0	37.5	62.5	Sites occurred in some younger stands (141-250 y) in all study areas, except NVI. Few sites occurred in ≤140 y stands (only WVI and SMC) and most of these included distinct veteran or dominant trees.
	Ground-based	0	-	-	-	-	
QCI	Telemetry	7	0.0	0.0	42.9	57.1	
	Ground-based	19	0.0	0.0	0.0	100.0	
NVI	Telemetry	0	-	-	-	-	
	Ground-based	25	0.0	0.0	0.0	100.0	
SEVI	Telemetry	0	-	-	-	-	
	Ground-based	14	0.0	0.0	85.7	14.3	
SMC	Telemetry	101	3.0	10.9	19.8	66.3	
	Ground-based	22	0.0	0.0	0.0	100.0	
WVI	Telemetry	34	0.0	2.9	2.9	94.1	
	Ground-based	43	0.0	0.0	0.0	100.0	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table 10. Proportion of murrelet sites, by tree height class.

Study area	Dataset	n [a]	Class [b] <20 (m)	20-28 (m)	29-37 (m)	>37 (m)	Comments
CMC	Telemetry	8	25.0	62.5	12.5	0.0	Variation in tree heights of stands occurs within all study areas. Although different height classes may dominate, most sites have tree heights ≥29 m. The CMC has proportionately more sites within the 20-28 m height class, but estimates are based on 1:40 000 airphotos.
	Ground-based	0	-	-	-	-	
QCI	Telemetry	7	0.0	28.6	71.4	0.0	
	Ground-based	19	0.0	0.0	26.3	73.7	
NVI	Telemetry	0	-	-	-	-	
	Ground-based	25	0.0	4.0	72.0	24.0	
SEVI	Telemetry	0	-	-	-	-	
	Ground-based	14	0.0	0.0	14.3	85.7	
SMC	Telemetry	101	15.8	22.8	47.5	13.9	
	Ground-based	22	0.0	18.2	77.3	4.5	
WVI	Telemetry	34	8.8	17.6	73.5	0.0	
	Ground-based	43	0.0	4.7	37.2	58.1	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table 11. Proportion of murrelet sites, by stand crown closure class.

Study area	Dataset	n [a]	Class [b] <26% (%)	26-35% (%)	36-65% (%)	≥66% (%)	Comments
CMC	Telemetry	8	12.5	12.5	75.0	0.0	Most sites occur in the 36-65% class. <26% closure indicates sites with rocky, unproductive areas, or two-layer stands with a top layer of veterans.
	Ground-based	0	-	-	-	-	
QCI	Telemetry	7	0.0	14.3	85.7	0.0	
	Ground-based	19	5.3	10.5	84.2	0.0	
NVI	Telemetry	0	-	-	-	-	
	Ground-based	25	0.0	0.0	100.0	0.0	
SEVI	Telemetry	0	-	-	-	-	
	Ground-based	14	0.0	7.1	92.9	0.0	
SMC	Telemetry	101	16.8	13.9	62.4	7.0 [c]	
	Ground-based	22	0.0	0.0	100.0	0.0	
WVI	Telemetry	34	8.8	5.9	64.7	20.6 [c]	
	Ground-based	43	4.7	7.0	86.0	2.3	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.
[c] 2% of nests occurred in the >75% class for SMC, but 0% of nests occurred in the >75% class for WVI.

Table 12. Proportion of murrelet sites, by stand vertical complexity class.

Study area	Dataset	n [a]	Class [b,c] 1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	Comments
CMC	Telemetry	8	0.0	37.5	50.0	12.5	0.0	Most sites occur in Uniform or Non-Uniform stands. Few sites occur in Very Non-Uniform stands (ground-based–WVI, QCI) or Very Uniform stands (telemetry–WVI). Higher proportional use of Uniform Stands in the CMC study area may be attributed to use of 1:40 000 airphotos.
	Ground-based	0	-	-	-	-	-	
QCI	Telemetry	7	0.0	14.3	42.9	42.9	0.0	
	Ground-based	19	0.0	0.0	10.5	52.6	36.8	
NVI	Telemetry	0	-	-	-	-	-	
	Ground-based	25	0.0	0.0	48.0	52.0	0.0	
SEVI	Telemetry	0	-	-	-	-	-	
	Ground-based	14	0.0	0.0	64.3	28.6	0.0	
SMC	Telemetry	101	0.0	11.9	70.3	17.8	0.0	
	Ground-based	22	0.0	0.0	59.1	40.9	0.0	
WVI	Telemetry	34	2.9	8.8	64.7	23.5	0.0	
	Ground-based	43	0.0	0.0	51.2	46.5	2.3	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.
[c] 1 = Very Uniform, 2 = Uniform, 3 = Moderately Uniform, 4 = Non-Uniform and 5 = Very Non-Uniform.

Table 13. Proportion of murrelet telemetry sites within the CMMRT's (2003) recommended habitat classes, by parameter, for two study areas.

Parameter	CS [a] Most Likely (%)	CS [a] Moderately Likely (%)	CS [a] Least Likely (%)	DS [a] Most Likely (%)	DS [a] Moderately Likely (%)	DS [a] Least Likely (%)
Stand age	94.1	2.9	2.9	66.7	19.6	13.7
Tree height	5.9	85.3	8.8	60.8	23.5	15.7
Crown closure	64.7	26.5	8.8	61.7	19.6	18.6
Vertical complexity	88.2	8.9	2.9	87.3	11.8	9.8
Elevation	91.2	11.8	0	75.5	23.5	9.8

[a] CS, n=34. DS, n=102.

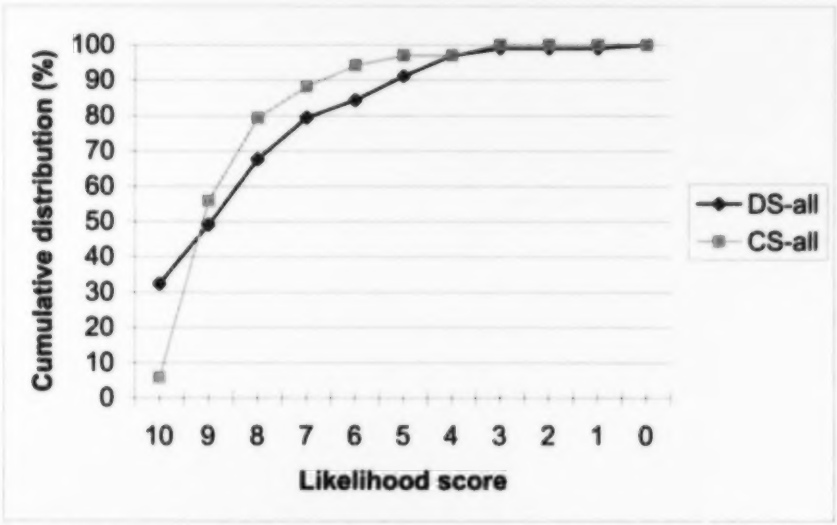

Figure 1. Cumulative distributions of overall likelihood scores for the DS and CS study areas. Based on age, height, crown closure, vertical complexity, and elevation, where 10 is the maximum possible overall score.

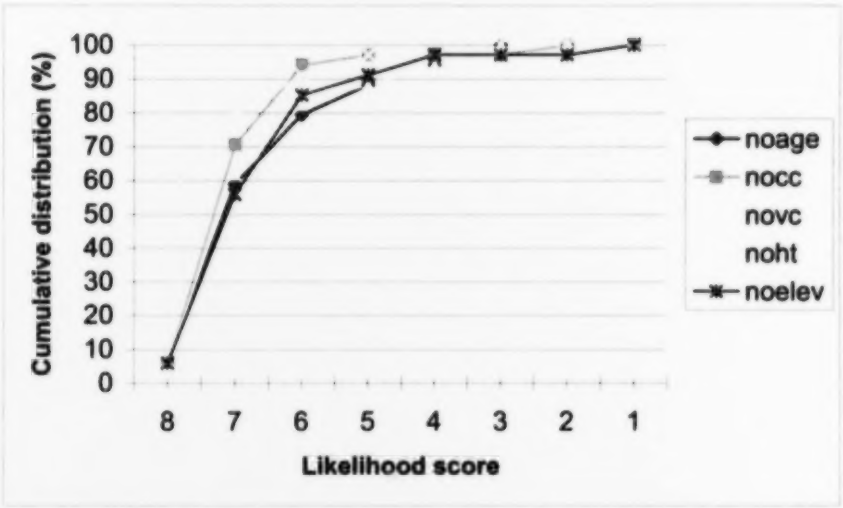

Figure 2a. Cumulative distributions of likelihood scores for the CS study area (n=34) from combinations of four parameters (maximum score of 8). Curves are: noage = stand age eliminated, noht = tree height eliminated, novc = stand vertical complexity eliminated, noelev = elevation eliminated, nocc = stand crown closure eliminated.

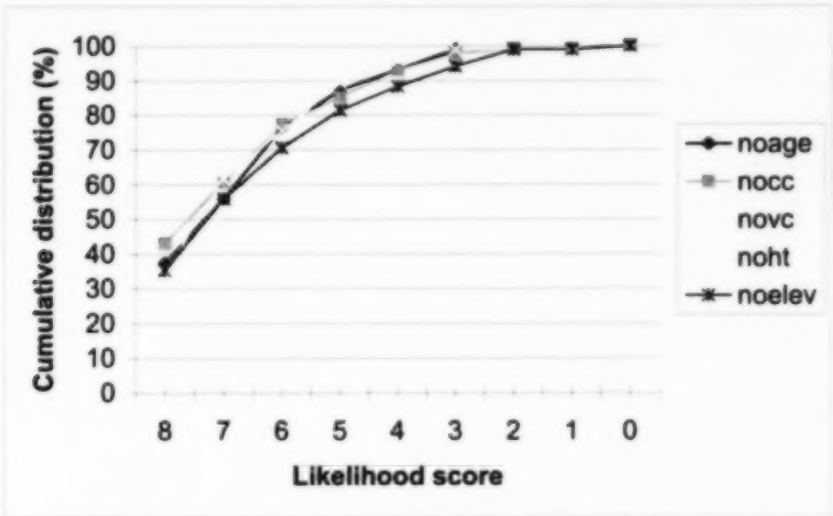

Figure 2b. Cumulative distribution of likelihood scores for the DS study area (n=102) from combinations of four parameters (maximum score of 8). Curves are: noage = stand age eliminated, noht = tree height eliminated, novc = stand vertical complexity eliminated, noelev = elevation eliminated, nocc = stand crown closure eliminated.

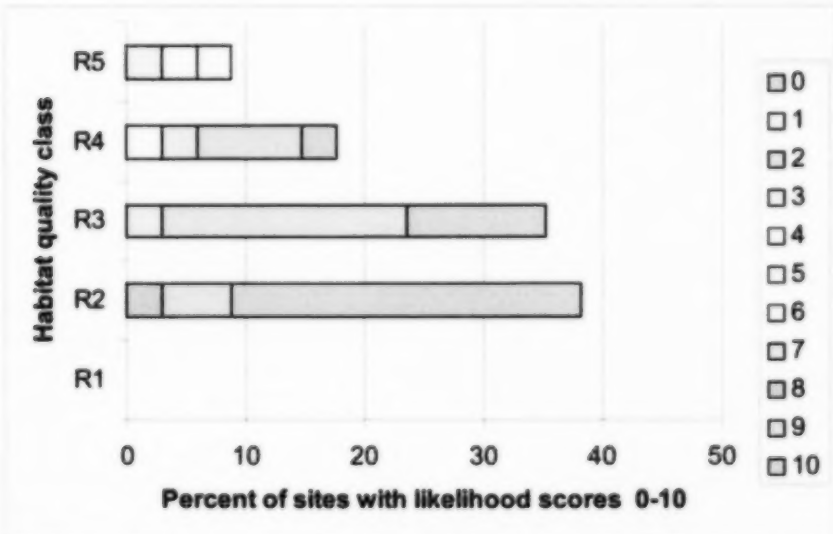

Figure 3a. Proportion of total telemetry nest sites (n=34) by likelihood scores within each habitat quality class at the CS study area.

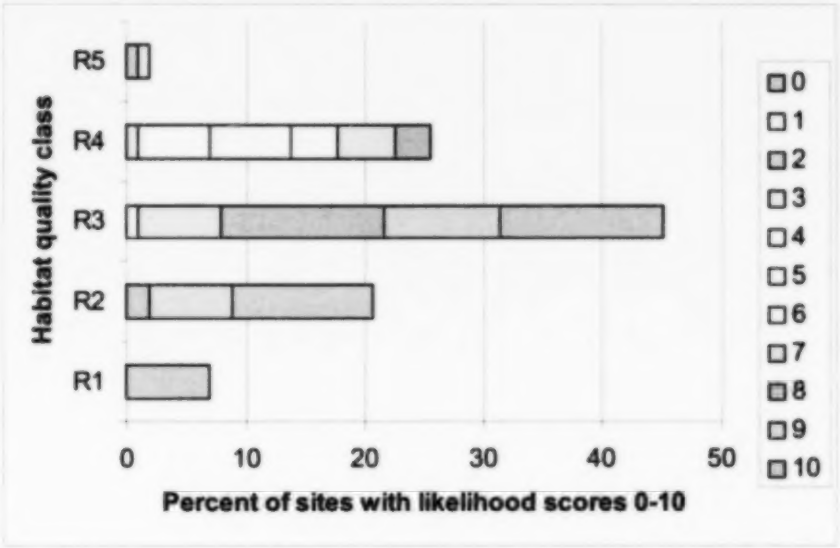

Figure 3b. Proportion of total telemetry nest sites (n=102) by likelihood scores within each habitat quality class at the DS study area.

objectives that may have relied on non-random selection of watersheds or sites within particular sets of watersheds. In these cases, field methods would not be biased within the range of habitats to which they were applied, but they may be biased for our study.

The second reason for the observed differences could be that we may have introduced a bias by selecting a sample of ground-based murrelet sites based on our ability to locate them on airphotos rather than by selecting them randomly. A bias could have been introduced if the murrelet behaviours used to select samples were associated with particular types of murrelet sites (e.g., more visual detections made by Rodway and Regehr 2000 and 2002 were along stream channels than in adjacent forest).

The third reason is that the sample of ground-based murrelet sites may be biased by lack of access by observers to some sites used by murrelets (Bradley 2002). For example, in the case of the DS study area, 46% of the telemetry nest sites located on airphotos could not be accessed, and of these, 20% would not be accessible even with helicopter support (Lank et al. 2003). Similarly, 15% of telemetry nest sites in the CS study area were not accessible with helicopter support. In our study, we used most of these telemetry nest sites by interpreting habitat parameters on airphotos. The greatest differences between telemetry nest sites and ground-based murrelet sites in the DS study area occurred with respect to the murrelets' greater use of patches and their greater use of sites with <40% of forest cover >140 years old (Tables 6 and 7).

The fourth reason is that the sample of telemetry nest sites is derived from only two study areas, which could, by chance, represent unusual nesting habitats relative to those geographic areas used by murrelets elsewhere. However, because the murrelets nested productively over the range of habitats at these study areas (Zharikov et al. in prep.) we see no compelling reason to adopt this explanation.

Whether apriori choice of study area and/or limited accessibility account for the difference in results, we suggest the principle telemetry study area—DS—represents the use of patch and scrubby sites particularly well.

Parameter Summaries: Compilation Interpretation

Despite the differences noted above, both the telemetry and ground-based compilations of murrelet sites provided overlap in their general interpretation of murrelet habitat use. Inter-regional differences occurred between some habitat parameters, e.g., use of forest patches. The variation in habitat used by murrelets may have resulted because of differences in habitat availability due to ecosystem type, topography, and disturbance histories. Airphoto interpreters should not necessarily exclude habitats described at the tails of the nesting habitat distributions (i.e., those least like "benchmark stands" of best potential habitats), but undertaking follow-up habitat assessments (by ground or helicopter) of these sites will be important. Furthermore, interpreters must take the ecosystem into consideration. For example, tree height is not necessarily limiting, particularly where tree species,

elevation, and latitude can influence tree height. Waterhouse et al. (2002) suggested that tree height is important when evaluating murrelet habitat, and they suggested its importance is relative to stand structure such that the suitability of shorter stands improved if the stand was more vertically complex.

The CMMRT's (2003) current recommendation for the potential acceptance of small natural forested patches as part of a set of reserves is consistent with our findings. Of the five recommended parameters that we described from the CMMRT's criteria, the recommendations for classifying stand crown closure classes (Appendix D) appear least consistent with our findings. Murrelets used stands with <26% crown closure more often than stands with >75% crown closure, although they were both classified as Least Likely (Appendix D). But stands with <26% closure were mostly attributable to occurring in rocky nonproductive areas, to containing veterans, or to being two-layer stands. Therefore, airphoto interpreters should be cautious when identifying these stands as potential habitat and they should ensure that other forest attributes consistent with murrelet habitat occur at the site.

A non-trivial portion of murrelet sites (e.g., Table 13) would not be classified as higher quality habitats using the preliminary habitat quality classification, although we suspect more would classify as higher quality habitat using the newer, revised classification (Donaldson 2003). Also, the likelihood scoring based on the equal weighting of the five parameters did not capture all telemetry nest sites (Figure 3). But with the likelihood scores, sites with higher total scores were produced even when some individual parameters scored low according to the CMMRT's criteria, which was not the case with the habitat classes. Exploration of the contribution of each parameter to the overall likelihood scores (Figures 2a and 2b) indicated that tree height and crown closure might contribute least to defining suitable habitat on airphotos. But these findings are preliminary and require further testing by use/availability analyses and by multiple regression techniques. The importance of tree height as an indicator of stand quality may vary with, or be reduced by, stand vertical complexity (Waterhouse et al. 2002). Bahn and Newsom (2002) report that in stands of smaller trees at higher elevations the density of trees with platforms was similar to the density in stands of larger trees at lower elevations. Therefore, when describing murrelet habitat, the importance of tree height may change with elevation.

The usefulness of crown closure for identifying good quality habitat is also not clear. Waterhouse et al. (2002) did not find that crown closure predicted habitat use for stand-level comparisons in the DS study area. Bahn and Newsom (2002) suggest that crown closure was most useful as a predictor of stand use, but only where >75% closure stands limited murrelet access and <26% closure stands failed to provide cover for suitable nest trees.

Classifying sites may be ineffective for the same reasons that scoring sites can be ineffective, i.e., difficulties associated with the use or weighting of some parameters such as tree height and crown closure. Further, differences between likelihood scores and classes might have resulted because the preliminary habitat quality classification uses information in addition to that considered for scoring, as follows:

1. Canopy complexity. Presence of gaps and effects of topographic complexity that are not necessarily reflected by the stand vertical complexity.

2. Height differences within the CMMRT's recommended height classes, e.g., taller verses shorter trees within the 29 to 37 m class.

3. Elevation is considered only indirectly through its relationship with forest parameters as forest structure changes along the elevational gradient.

Donaldson (2003) has changed the original classification to more closely follow the criteria used by the CMMRT (2003). As a result of this change a higher proportion of the sample of the telemetry nest sites would now rank as higher quality habitat (High and Very High) because some of the stands that originally ranked lower (i.e., Moderate) are now ranked higher, based primarily on tree height. Further testing of the other additional information (i.e., canopy complexity and elevation) is needed. Canopy complexity is described by several of the novel parameters (Appendix C), but canopy complexity as an individual parameter was not defined and tested. Rather, recognition of its use as a parameter originates with our study. Canopy complexity describes the overall variability in the canopy structure by incorporating vertical complexity, topographic complexity, and the distribution and abundance of canopy gaps. Topographic complexity is defined by Donaldson (2003)[8] and also requires testing.

The habitat quality classification follows the current direction of the CMMRT's (2003) criteria; the criteria incorporate the implied greater risk of parameters described as "Least Likely" relative to the parameters described as "Most

[8] Topographic complexity may enhance the suitability of forest stands for nesting by breaking up the continuity of the forest canopy, and may thus improve access to the canopy for nesting murrelets (CMMRT 2003). Topographic complexity is a subjective assessment of small irregularities in the stand topography, which creates small gaps and variability in the canopy structure. Features such as small rock outcrops, avalanche chutes, and gullies contribute to canopy complexity and do not necessarily affect the vertical complexity classification. Slope also contributes to variation in the canopy height and to canopy gaps. Slopes or areas with irregularities would generally be ranked higher than less steep slopes or areas without irregularities, but topographic complexity should not overrule canopy structure in ranking habitat. However, it is recommended that topographic complexity be considered in the overall habitat ranking because it has the potential to increase or decrease the stand ranking by a class, particularly for relatively uniform stands where vertical complexity is low (Donaldson 2003).

Likely". The preliminary habitat quality classification and the newer, proposed classification (Donaldson 2003) may be most useful for identifying those habitats with least risk, i.e., those displaying a higher likelihood of murrelet habitat suitability as per the CMMRT's criteria. The stands that ranked Very High and High in the habitat classification scheme also scored high in the likelihood scheme, therefore these sites provide airphoto interpreters with reliable examples of benchmark habitat. The main advantage of scoring verses classifying is that a score provides a means to consider all sites equally by accounting for the potential variation in quality of individual parameters at sites. For example, scoring allows for the fact that a site may be higher quality, although the score includes parameters scored "Least Likely".

The compilations indicate that not all murrelet sites will necessarily fall within higher quality habitat and some nests may fall within habitat considered unsuitable—depending on where the cut-off between suitable and unsuitable is determined to be in terms of murrelet management. Therefore, to ensure the effective management of the murrelet population, land managers must be able to estimate the proportion of murrelet sites likely to occur in "unsuitable" habitat. Cumulative distribution curves of likelihood scores—if available for different study areas—may be one tool that managers can use to make this estimate; but, the implicit assumption is that the curves represent the distribution of all nest sites in the landscapes. For example, in the DS study area, if habitat that scored ≥5 was considered suitable, land managers could assume with some certainty that 10% of murrelet nest sites occur in habitats not identified for murrelet management on airphotos (Figure 1). Land managers could then assess the status of low-scored habitat (i.e., <5) and its long-term availability for use by this portion of the breeding population. A similar approach could be used with the newer, proposed classification scheme (Table 2). For example, if the above approach was applied using the telemetry nest sites in the DS study area from the preliminary classification, between 2 and 25.5% of the telemetry nest sites would probably be excluded from management areas (Table 8).

Reference Photos

We selected a subset of 47 of the 274 sites distributed over four of the six conservation regions as reference airphotos (Table 14). This collection of reference airphotos will assist airphoto interpreters when they are applying the draft standards (Donaldson 2003), because reference airphotos provide benchmarks of high-quality habitat types and they represent the range and variability of habitat interpreted at the murrelet sites in each study area. Thus reference airphotos can reduce the uncertainty associated with habitat ranking. Where appropriate, airphotos of the different study areas can be considered by ecosystem and/or location (Table 14).

CONCLUSIONS

In general, airphoto interpretation shows promise for identifying murrelet habitat quality, as indicated by the general distributions of murrelet sites on airphotos with respect to many of the parameters ranked. Although we determined some differences between sites grouped by the different sampling methods, the overall parameter summaries and reference airphotos are nevertheless useful for guiding airphoto interpreters as to the range and distribution of habitat used by nesting murrelets. However, we have not tested the distributions documented here against random samples from the landscapes of interest. We could not make clear inferences on how important combinations of parameters are for identifying murrelet nesting habitat relative to those types of forests available in the landscape. Tests of murrelet habitat use based on habitat classifications—whether using likelihood scoring or habitat quality classification (Donaldson 2003)—are needed to help reduce these uncertainties. For example if Moderate and Low habitats are selected relative to their availability we suggest these habitat quality classes could be ranked higher during airphoto interpretation. But if murrelets do not select Moderate or Low habitats then we may need to examine other parameters for ranking habitat, or re-evaluate the usefulness of interpreting habitat via airphotos. This information could also help improve the habitat quality classification scheme, i.e., in terms of choosing which parameters to use to interpret airphotos and which to use to describe suitable habitat. Finally, if land managers used measures of productivity with respect to habitat parameters—such as relative nesting success—this would provide them with further information about the possible effectiveness of management choices.

Given the broad range of habitats currently used by murrelets in coastal British Columbia, airphoto interpretation may not effectively identify all potential habitats; the use of additional methods is justified to help confirm

Table 14. Total number of murrelet sites identified on airphotos, by study area.

Study area	Total airphotos (no. of sites)	Reference airphotos (no. of sites)
CMC	8	0
QCI	26	9
NVI	25	6
SEVI	14	4
SMC	124	13
WVI	77	15

habitat use, or to help rethink how well murrelets discriminate habitat and at what spatial scale. However, confirmation of suitable habitat over a large area of land will be costly, whether surveys are conducted by ground or helicopter (CMMRT 2003). Furthermore, helicopter assessment methods need to be tested for effectiveness as a planning tool. Alternatively, land managers may need to consider that a portion of the total population of nesting murrelets will not be managed within habitats that can be delineated on maps. Some of this low-ranked habitat probably includes unmerchantable stands, which reduces the risk that important unidentified murrelet habitat will be harvested. Merchantability of stands should be quantified relative to habitat classification to provide land managers with options for managing murrelet populations. For example, using the classification in Table 2, the stands we ranked as Low or Nil habitat quality were probably unmerchantable, and portions of stands ranked as Moderate habitat quality were also probably unmerchantable. However, assessment of merchantability differs by Tree Farm License and Timber Supply Area, and, locally, changes over time.

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APPENDIX A
ABBREVIATIONS USED IN THE REPORT

Abbreviations for study areas

CMC – Central Mainland Coast murrelet conservation region

QCI – Queen Charlotte Islands / Haida Gwaii murrelet conservation region

SMC – Southern Mainland Coast murrelet conservation region

SEVI – Southeast Vancouver Island murrelet conservation region

WNVI – West and North Vancouver Island murrelet conservation region

NVI – Northern Vancouver Island murrelet conservation subregion, including north of Brooks Peninsula (west Vancouver Island); otherwise bounded by the SEVI region.

WVI – Western Vancouver Island murrelet conservation subregion, including south of Brooks Peninsula on the west coast; otherwise bounded by the SEVI region.

DS – Desolation Sound research area (Simon Fraser University)

CS – Clayoquot Sound research area (Simon Fraser University)

Other abbreviations

CMMRT – Canadian Marbled Murrelet Recovery Team

CWH – Coastal Western Hemlock biogeoclimatic zone

MH – Mountain Hemlock biogeoclimatic zone

CDF – Coastal Douglas-fir biogeoclimatic zone

APPENDIX B

MARBLED MURRELET SITES IN COASTAL BRITISH COLUMBIA: SUMMARY OF LOCATIONS USED IN THIS STUDY, AS IDENTIFIED BY TELEMETRY AND GROUND-BASED METHODS

Study area	Source of observation	General area of observation	Total observations used for compilation (no.)	Total observations available for compilation (no.)	Type of observation selected for use
Central Mainland Coast (CMC)	Kaiser and Keddie (1999)	Mussel Inlet	8	8	Subset of 8 telemetry locations confirmed on airphotos by G. Keddie.[a]
Queen Charlotte Islands (QCI)	McLaughlin (1996)	Kermode Creek Chadsey Creek	3	3	Audio-visual locations supplied on airphotos by A. Cober.[b]
	Materi et al (1997, 1998)	Crescent Inlet Botany Inlet Fairfax Inlet	8	17	Audio-visual locations selected by detection type (i.e., bird lands or leaves a tree, or does aerial dive). All sites indicate below canopy and other occupied activities.
	Deschesne and Smith (1997)	Eden and Naden watersheds	2	2	Nest and chick locations supplied on airphotos by D. McInnis.[c]
	Deschesne and Smith (1997)	Tartu Inlet Eden Landscape Unit	4	24	Audio-visual locations selected as those with a greater number of detections from 1995 and 1996. Maps provided by A. Hetherington.[d]
	Reimchen (1991)	Naikoon Park Athlow Bay	2	2	Relied on descriptions of behaviour activities in report.
	Manley et al. (2001)	Skidegate Channel (east narrows to end of Chaatl Island)	7	7	Telemetry locations confirmed by I. Manley.[e]
Northern Vancouver Island (NVI)	Waterhouse and Harestad (1999)	Tsitika River	1	1	Audio-visual detection on potential nest tree. Located on airphoto by L. Waterhouse.[f]
	Schroeder (2003)	Clanninnick River	1	1	Audio-visual detection on potential nest tree, confirmed on airphoto by B. Schroeder.[g]
	Harper et al. (2003)	TFL 37 (various)	23	23	Audio-visual detections provided on airphotos by J. Deal.[h]

Table continued on next page.

Appendix B, continued

Study area	Source of observation	General area of observation	Total observations used for compilation (no.)	Total observations available for compilation (no.)	Type of observation selected for use
Southeast Vancouver Island (SEVI)	Burger et al. (2000)	Victoria watersheds (CRD) Nanaimo/ Cowichan Rivers (TimberWest and Weyerhauser)	14	14	Nest or audio-visual detections provided on airphotos by A. Young.[i]
Southern Mainland Coast (SMC)	Manley (1999)	Bunsters Hills	7	56	Nest locations on airphotos by I. Manley.[e] Selected subset based on overlap and distribution.
	Crocker and Manley (1997) Manley and Jones (1999) Jones and Manley (2001)	Homfray River Caren Range Brittain River Skwawka River Chapman Creek Jervis Inlet	13	19	Nests and audio-visual locations on airphotos. Most areas surveyed after initial application of habitat algorithm. Located on airphotos by T. Jones.[j] Selected subset based on location overlap.
	Waterhouse (unpublished data)[f]	Capilano watershed	2	2	Audio-visual locations on airphotos by L. Waterhouse.[f]
	Lougheed (2000) Cooke and Lank (2002)	Desolation Sound (Powell Lake to Toba Inlet, including E. Rhodonda Island)	102	102	Telemetry locations confirmed on airphotos by R. Bradley, L. Lougheed, and C. Thiessen.[a]

Table continued on next page.

Appendix B, concluded

Study area	Source of observation	General area of observation	Total observations used for compilation (no.)	Total observations available for compilation (no.)	Type of observation selected for use
Western Vancouver Island (WVI)	Lindsay et al. (2000)	Caycuse River Walbran River Hemmingsen River Carmannah River	10	10	Audio-visual locations on airphotos provided by D. Lindsay.[k]
	Burger and Bahn (in press) Burger (unpublished data)[l]	Carmannah/ Walbran River Klanawa River Southwest coast	10	27	Nests and audio-visual locations, (except Klanawa R.) from A. Burger.[l] Sample was reduced based on our ability to locate the original sites on airphotos, and due to overlap of sites.
	Schroeder (1999, 2001) Schroeder and Henderson (2000, 2001) Schroeder and Webster (2000)	Toquart River Effingham River Nitinat Lake Carmannah River	17	26	Audio-visual locations provided on airphotos by B. Schroeder.[g] Sample was reduced due to overlap of sites.
	Rodway and Regehr (2002)	Flores Island Bulson Creek Ursus Creek Tranquil Creek Pretty Girl River	7	80	Audio-visual locations mapped in report. Subset based on audio-visual detection type (i.e., bird lands in or leaves a tree, or does aerial dive) and below canopy activity (6/7 sites).
	Cooke and Lank (2002) Lank and Cooke (2003)	Herbert Inlet Catface Range Megin River Moyeha River Ursus Creek Cypre River Buttle Lake	34	34	Telemetry locations confirmed on airphotos by G. Keddie and C. Thiessen.[a]

[a] Glen Keddie, Conrad Thiessen, Russ Bradley, and Lynn Lougheed were wildlife technicians in the Dept. of Biology, Simon Fraser University, Burnaby, BC.
[b] Alvin Cober, Ecosystem Specialist, BCMWLAP, Queen Charlotte City, BC.
[c] Dwayne McInnis, Tecfor Resources Ltd., Queen Charlotte City, BC.
[d] Ann Hetherington, Ecosystem Specialist, Skeena Region, BCMWLAP, Smithers, BC.
[e] Irene Manley, consultant, Wardner, BC.
[f] Louise Waterhouse, Wildlife Ecologist, Coast Forest Region, BCMOF, Nanaimo, BC.
[g] Bernard K. Schroeder, consultant, Nanaimo, BC.
[h] John Deal, Habitat Forester, Englewood Division, Canadian Forest Products, Woss, BC.
[i] Anna Young, consultant, Victoria, BC.
[j] Toby Jones, consultant, Maple Ridge, BC.
[k] Dave Lindsay, Biologist, TimberWest, Crofton, BC.
[l] Dr. A. Burger, Dept. of Biology, University of Victoria, Victoria, BC, unpublished data.

APPENDIX C

ADDITIONAL NOVEL STAND PARAMETERS THAT MAY BE ASSOCIATED WITH MURRELET NESTING HABITAT

Based on current knowledge of habitat use by murrelets (e.g., Burger 2002), we defined novel parameters for interpreting murrelet habitat from airphotos (Table C-1). These parameters need testing (e.g., use/availability tests) before we can determine their importance for describing murrelet habitat; but we include the compilations now to ensure this information is available for reference if future research confirms the importance of the parameters.

We followed the analyses outlined in the main report. Consistent with our findings in the main report, the interpretation of parameters in 100-m and 300-m radius overlapping plots, from either the DS or CS study areas, did not differ or differed for <10% of samples (Table C-2). Only frequency of small gaps in the DS study area changed, as small gaps appeared to be more prevalent in the 300-m radius plots than in the 100-m radius plots (Chi-square=8.96, P=0.002).

Similarly our comparison of the datasets obtained by telemetry and ground-based methods (SMC and WVI) confirms that these two samples were not necessarily representing the same distribution of habitat used by murrelets, but results were not consistent between study areas (Table C-3). For the SMC, a smaller proportion of telemetry nest sites than ground-based murrelet sites occurred in Tree Cover Pattern Class 9 stands (Table C-3). For both study areas, large gaps occurred in significantly greater proportions in the samples of telemetry nest sites while small gaps were more often prevalent and often occurred in greater proportions in the sample of ground-based murrelet sites (Table C-3). Large trees occurred in all samples of murrelet sites (telemetry and ground-based). However, in the WVI study area, large trees were more often considered prevalent than sporadic in occurrence at ground-based murrelet sites than at telemetry nest sites. In addition, for WVI, some large trees in the ground-based murrelet sites occurred as clumps, whereas none did at the telemetry nest sites. Meso-slope position also differed significantly for WVI, where a higher proportion of the samples of ground-based murrelet sites occurred in the lower slope position, and smaller proportions occurred in each of the mid and upper slope categories (Table C-3).

Telemetry nest sites are summarized using 100-m radius plots while the ground-based murrelet sites (audio-visual sites, and sites with nests located from ground searches) are presented using 300-m radius plots (Tables C-4 to C-10). We do not provide a discussion of these findings because the importance of the "novel parameters" for interpretation is unknown.

Table C-1. Novel parameters for interpreting murrelet habitat on airphotos, including reasoning of potential value for murrelets.

Parameter	Definition	Potential value for murrelets
Tree cover pattern	Nine cover patterns, ranging from limited patches (1) to discontinuous but extensive occurrences to continuous coverage with very few gaps (9). Tree cover pattern was estimated for the stand including areas that extended beyond the plot radius perimeter. For the analysis we combined patterns 1 to 4 (very patchy limited tree cover) and patterns 5 to 8 (fairly continuous tree cover, but several significant canopy gaps) and retained pattern 9 (continuous cover and very few gaps).	Gaps may be associated stand access for the murrelet (Manley 1999; Waterhouse et al. 2002).
Large gaps (≥1 tree length wide)	Often produced by topographic influences. Significant openings within the canopy, thus contributing to vertical complexity. Occurrence *Prevalent* occupies >20% of stand area. *Sporadic* occupies 5 to 20% of stand area. *None* occupies <5% of stand area.	
Small gaps (<1 tree length wide)	Smaller openings within canopy, thus contributing to vertical complexity. Usually more prevalent than large gaps. Stands have more small gaps when both crown closure and vertical complexity are high compared to when crown closure is high but vertical complexity is low. Occurrence *Prevalent* occupies >20% of stand area. *Sporadic* occupies 5 to 20% of stand area. *None* occupies <5% of stand area.	
Large trees	Dominant trees with large crowns at least 5 m above the main canopy of the stand. This parameter is particularly useful for capturing veteran trees not necessarily described in the layer. Occurrence *Prevalent* >20% of stems are above main canopy. *Sporadic* 3 to 19% of stems are above main canopy. *None* <3% of stems are above main canopy. Pattern of distribution *Clumped* and/or *scattered.*	Murrelets select for larger trees in nest patches (Manley 1999; Nelson and Wilson 2002), and large above-canopy trees might, to birds in flight, act as visual cues that potential nesting platforms are available.
Meso slope (Site position meso) (Luttermerding et al. 1990)	The relative position of the sampling site within the local catchement area, usually having a vertical difference of 3 to 300 m. *Low* = lower-slope, toe, flat, and depressions. *Mid* = mid-slope. *Upper* = upper slope and crest.	Murrelet nesting habitats are positively associated with more productive sites (Burger 2002; Rodway and Regehr 2002). Water-receiving lower slopes are often more productive and grow larger trees; whereas water-shedding upper slopes are usually less productive and grow smaller trees.[a]
Species composition	Describes live tree species present and estimates the percentage of each in the polygon by proportion of basal area or density. Species composition adds up to 100%.	Tree species has not been related to murrelets' selection of nest trees although some potential preferences have been hypothesized (Burger 2002).

[a] Paul Courtin, Research Pedologist/Ecologist, Coast Forest Region, BCMOF; Nanaimo, BC; personal communication July 17, 2003.

Table C-2. Proportion of 100-m and 300-m radius plots at two study areas that are similarly described by parameter class estimates.[a]

Parameter	Study area	
	DS (%)	CS (%)
Tree cover pattern	91	93
Large gaps	100	93
Small gaps	74 [b,c]	97 [d]
Large trees	94	84
Meso slope	100	93

[a] DS, n=32. CS, n=31.
[b] Sample large enough to test for statistical difference.
[c] DS, n=31.
[d] CS, n=30.

Table C-3. Significant results of two-tail tests[a] of parameter estimates in 300-m radius plots sites identified for telemetry methods and ground-based sites, in two study areas.

Parameter	Study area	Telemetry nest sites (n=32 for SMC, n=31 for WVI) [b]	Ground-based murrelet sites (n=22 for SMC, n=43 for WVI) [b]	P (P≤0.05)
Tree cover pattern	SMC	59% Class 9 41% Class 1-8	95% Class 9 5% Class 1-8	0.004
	WVI	84% Class 9 16% Class 1-8	79% Class 9 21% Class 1-8	0.61
Large gaps, occurrence [c]	SMC	53% present 47% absent	23% present 77% absent	0.05
	WVI	45% present 55% absent	21% present 79% absent	0.04
Small gaps, occurrence	SMC [d]	54% prevalent 46% sporadic	86% prevalent 14% sporadic	0.02
	WVI [d]	61% prevalent 39% sporadic	95% prevalent 5% sporadic	0.0005
Large trees				
Occurrence	SMC	50% prevalent 34% sporadic 16% none	68% prevalent 32% sporadic 0% none	0.12
	WVI [d]	31% prevalent 69% sporadic	91% prevalent 9% sporadic	<0.0001
Distribution	SMC	6% clumped 78% scattered 22% none	14% clumped 86% scattered 0% none	0.12
	WVI [d]	0% clumped 100% scattered	9% clumped 91% scattered	0.06
Meso slope	SMC	Low = 41% Med = 44% Upper = 16%	Low = 55 Med = 45% Upper = 0%	0.13 [e]
	WVI	Low = 39% Med = 39% Upper = 23%	Low = 79% Med = 19% Upper = 2%	0.001

[a] Wilcoxon sign-rank, Pearson Chi-square, or Fisher's Exact tests.
[b] n is the total number of sites per study area for the telemetry or ground-based datasets. The exceptions are for telemetry large trees and tree cover pattern in WVI, n=29.
[c] Parameter treated as present or absent within 300-m radius plot.
[d] Parameter classes reduced for test
[e] Violates 20% rule (Zar 1984).

Table C-4. Proportion of murrelet sites, by tree cover pattern classes.

Study area	Dataset	n [a]	Class [b] 1-4 (%)	5-8 (%)	9 (%)	Comments
CMC	Telemetry	8	0.0	62.5	37.5	Tree cover pattern is continuous (9) for a greater proportion of sites, except those in the CMC study area, and differences are small for the SEVI and SMC study areas (telemetry). Low numbers of telemetry sites (WVI and SMC) occur in areas with sporadic or patchy tree cover (classes 1-4), and they were usually associated with unusual sites, such as cliff nests.
	Ground-based	0	-	-	-	
QCI	Telemetry	7	0.0	14.3	85.7	
	Ground-based	19	0.0	26.3	73.7	
NVI	Telemetry	0	-	-	-	
	Ground-based	25	0.0	12.0	88.0	
SEVI	Telemetry	0	-	-	-	
	Ground-based	14	0.0	35.7	57.1	
SMC	Telemetry	101	5.9	40.6	53.5	
	Ground-based	22	0.0	4.5	95.5	
WVI	Telemetry	34	2.9	8.8	85.3	
	Ground-based	43	0.0	20.9	79.1	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table C-5. Proportion of murrelet sites, by occurrence of large gap class.

Study area	Dataset	n [a]	Class [b] None (%)	Sporadic (%)	Prevalent (%)	Comments
CMC	Telemetry	8	25.0	75.0	0.0	Stands do not necessarily have large gaps; when large gaps do occur, frequency varies.
	Ground-based	0	-	-	-	
QCI	Telemetry	7	71.4	28.6	0.0	
	Ground-based	19	78.9	21.1	0.0	
NVI	Telemetry	0	-	-	-	
	Ground-based	25	80.0	16.0	4.0	
SEVI	Telemetry	0	-	-	-	
	Ground-based	14	57.1	28.6	14.3	
SMC	Telemetry	101	42.6	33.7	23.8	
	Ground-based	22	77.3	22.7	0.0	
WVI	Telemetry	34	52.9	41.2	5.9	
	Ground-based	43	79.1	16.3	4.7	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table C-6. Proportion of murrelet sites, by occurrence of small gap class.

Study area	Dataset	n [a]	Class [b] None (%)	Sporadic (%)	Prevalent (%)	Comments
CMC	Telemetry	8	0.0	62.5	37.5	Small gaps, unlike large gaps, occur in all stands and are more prevalent than the large gaps. But, in the CMC, SMC, and WVI study areas, small gaps are less prevalent in stands with telemetry nest sites than in stands with ground-based murrelet sites.
	Ground-based	0	-	-	-	
QCI	Telemetry	7	0.0	0.0	100.0	
	Ground-based	19	0.0	0.0	100.0	
NVI	Telemetry	0	-	-	-	
	Ground-based	25	0.0	20.0	80.0	
SEVI	Telemetry	0	-	-	-	
	Ground-based	14	0.0	7.1	92.9	
SMC	Telemetry	100	0.0	56.0	44.0	
	Ground-based	22	0.0	13.6	86.4	
WVI	Telemetry	33	0.0	45.5	54.5	
	Ground-based	43	0.0	4.7	95.3	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table C-7. Proportion of murrelet sites, by occurrence of classes for large trees.

Study area	Dataset	n [a]	Class [b] None (%)	Sporadic (%)	Prevalent (%)	Comments
CMC	Telemetry	8	50.0	50.0	0.0	Most stands have large trees, but they are not necessarily prevalent in the stand. Those stands without large trees include a small portion of telemetry stands from the WVI and SMC study areas, and these stands likely represent unusual locations (e.g., cliff nests). The CMC study area has a larger portion of stands without large trees; this may be due to the 1:40 000 airphotos.
	Ground-based	0	-	-	-	
QCI	Telemetry	7	0.0	42.9	57.1	
	Ground-based	19	0.0	0.0	100.0	
NVI	Telemetry	0	-	-	-	
	Ground-based	25	0.0	20.0	80.0	
SEVI	Telemetry	0	-	-	-	
	Ground-based	14	0.0	0.0	100.0	
SMC	Telemetry	101	17.8	40.6	41.6	
	Ground-based	22	0.0	31.8	68.2	
WVI	Telemetry	34	14.7	61.8	23.5	
	Ground-based	43	0.0	9.3	90.7	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table C-8. Proportion of murrelet sites, by distribution class for large trees.

Study area	Dataset	n [a]	Class [b] None (%)	Scattered (%)	Clumped (%)	Scattered & clumped (%)	Comments
CMC	Telemetry	8	50.0	37.5	12.5	0.0	Large trees, whether prevalent or sporadic, are usually scattered throughout the stand and not clumped.
	Ground-based	0	-	-	-	-	
QCI	Telemetry	7	0.0	100.0	0.0	0.0	
	Ground-based	19	0.0	73.7	15.8	5.3	
NVI	Telemetry	0	-	-	-	-	
	Ground-based	25	0.0	88.0	12.0	0.0	
SEVI	Telemetry	0	-	-	-	-	
	Ground-based	14	0.0	100.0	0.0	0.0	
SMC	Telemetry	101	17.8	73.3	8.9	0.0	
	Ground-based	22	0.0	86.4	13.6	0.0	
WVI	Telemetry	34	14.7	82.4	0.0	2.9	
	Ground-based	43	0.0	87.3	10.4	2.3	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table C-9. Proportion of murrelet sites, by meso slope classes.

Study area	Dataset	n [a]	Class [b] Low (%)	Mid (%)	Upper (%)	Comments
CMC	Telemetry	8	12.5	62.5	25.0	Low or Mid slope positions are used most often. Sites located in Upper slope locations are mostly attributable to the telemetry datasets.
	Ground-based	0	-	-	-	
QCI	Telemetry	7	14.3	71.4	14.3	
	Ground-based	19	73.7	26.3	0.0	
NVI	Telemetry	0	-	-	-	
	Ground-based	25	68.0	32.0	0.0	
SEVI	Telemetry	0	-	-	-	
	Ground-based	14	92.9	7.1	0.0	
SMC	Telemetry	102	41.2	39.2	19.6	
	Ground-based	22	54.5	45.5	0.0	
WVI	Telemetry	34	41.2	35.3	23.5	
	Ground-based	43	79.1	18.6	2.3	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

Table C-10. Proportion of murrelet sites, by dominant tree species in stand.

Study area	Dataset	n [a]	Class [b] Hw (%)	Cw (%)	Ss (%)	Fd (%)	Ba (%)	Yc (%)	Dr (%)	Comments
CMC	Telemetry	8	12.5	25.0	0.0	0.0	50.0	12.5	0.0	Leading species of trees varies among study areas and may be related to ecosystem differences. One coastal species, lodgepole pine (*Pinus contorta*), did not occur in any stand. Use of stands dominated by alder (*Alnus rubra*) is uncommon.
	Ground-based	0	-	-	-	-	-	-	-	
QCI	Telemetry	7	28.6	28.6	42.9	0.0	0.0	0.0	0.0	
	Ground-based	19	26.3	15.8	57.9	0.0	0.0	0.0	0.0	
NVI	Telemetry	0	-	-	-	-	-	-	-	
	Ground-based	25	72.0	20.0	0.0	8.0	0.0	0.0	0.0	
SEVI	Telemetry	0	-	-	-	-	-	-	-	
	Ground-based	14	14.3	0.0	0.0	85.7	0.0	0.0	0.0	
SMC	Telemetry	101	43.6	22.8	0.0	15.8	13.9	1.0	3.0	
	Ground-based	22	68.2	22.7	0.0	0.0	4.5	4.5	0.0	
WVI	Telemetry	34	35.3	44.1	0.0	0.0	17.6	2.9	0.0	
	Ground-based	43	41.9	25.6	18.6	0.0	14.0	0.0	0.0	

[a] n is the total number of sites per study area for the telemetry or ground-based datasets.
[b] Dash (-) indicates no sample.

APPENDIX D

GUIDELINES FOR SELECTING SUITABLE HABITAT FOR NESTING MURRELETS IN BRITISH COLUMBIA, ADAPTED FROM CMMRT (2003)

Feature	Most Likely	Moderately Likely	Least Likely
Distance from saltwater, all study areas [a] (km)	0.5-30	0-0.5 & 30-50	>50
Elevation (m)			
Central mainland coast (CMC) & northern mainland coast (NMC)	0-600	600-900	>900
Queen Charlotte Islands (QCI)	0-500	500-800	>800
All other study areas	0-900	900-1500	>1500
Stand age class, all study areas	9 (>250 y)	8 (141-250 y)	<8 (≤140 y)
Site index productivity classes, all study areas	Classes I & II	Class III	Class IV
Tree height class, all study areas [b]	4-7 (≥28.5 m)	3 (19.5-28.4 m)	<3 (<19.5 m)
Canopy closure class, all study areas	Classes 4, 5, & 6	Classes 3 & 7	Classes 2 & 8
Vertical canopy complexity, all study areas [c]	Moderately Uniform, Non-Uniform, & Very Non-Uniform	Uniform	Very Uniform

[a] Areas within 0.5 km of exposed shores tend to have less suitable habitat and higher densities of predators, but this might not apply to steep-sided fjords and inlets.
[b] Nests have been found in polygons ranked Height Class 1 or 2, but the nests were in larger trees than the polygon average.
[c] Vertical complexity ranked from least to most (see Waterhouse et al. 2002).

NOTES